

The Performance of the Satellite-borne Hyperion Hyperspectral VNIR-SWIR Imaging System for Mineral Mapping at Mount Fitton, South Australia

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Abstract – Satellite-based hyperspectral imaging became a reality in November 2000 with the successful launch and operation of the Hyperion system on board the EO-1 platform. Hyperion is a pushbroom imager with 220 spectral bands in the 400-2500 nm wavelength range, a 30 meter pixel size and a 7.5 km swath. Pre-launch characterization of Hyperion measured low signal to noise (SNR<40:1) for the geologically significant shortwave infrared (SWIR) wavelength region (2000-2500 nm). The impact of this low SNR on Hyperion's capacity to resolve spectral detail was evaluated for the Mount Fitton test site in South Australia, which comprises a diverse range of minerals with narrow, diagnostic absorption bands in the SWIR. Following radiative transfer correction of the Hyperion radiance at sensor data to surface radiance (apparent reflectance), diagnostic spectral signatures were clearly apparent, including: green vegetation; talc; dolomite; chlorite; white mica and possibly tremolite. Even though the derived surface composition maps generated from these image endmembers were noisy (both random and column), they were nonetheless spatially coherent and correlated well with the known geology. In addition, the Hyperion data were used to measure and map spectral shifts of <10 nm in the SWIR related to white mica chemical variations.

I. INTRODUCTION

Remote hyperspectral sensing for detecting and mapping, often subtle, mineralogical spectral signatures using airborne systems has been operational for a number of years [1]. As part of the US New Millennium Program (*faster, cheaper, better*), the launch of the EO-1 satellite platform in November 2000 introduced hyperspectral sensing of the Earth from space through its Hyperion system [2, 3, 4], albeit as a scientific experiment. The main objectives of the experiment are to validate space-based hyperspectral imaging and to initially provide science-quality hyperspectral data to science team members. The life of the mission is one year only (2 year goal), with the instrument performance verification being the emphasis for the first three months.

This study reports preliminary results for the Hyperion spectral validation site at Mount Fitton in South Australia, one of three sites chosen by the science team to evaluate Hyperion data for resolving surface spectral signatures throughout the 400-2500 nm wavelength region. This depends on accurate wavelength, radiometric and MTF calibration/characterization and adequate SNR.

II. EO-1 AND HYPERION

The EO-1 spacecraft is in sun-synchronous orbit at 705 km altitude flying 1 minute behind Landsat 7 passing over the equator in descending node at 10.01 AM. It carries three instruments onboard: the Advanced Land Imager (ALI); the Atmospheric Corrector (AC); and Hyperion [4]. Hyperion is a pushbroom spectral radiometer with two spectrometers that share the same fore-optics. A VNIR CCD senses the first 70 bands (400-1000 nm) and an HgCdTe SWIR detector senses channels 71-242 (900-2500 nm). The SNR was measured for a 60° solar zenith for 30% reflector with the results ranging from 190:1 for the visible to 38:1 for the 2100-2150 nm wavelength regime in the SWIR. The 256 spatial dimension of the detector array produces a 7.5 km wide ground swath with pixel size of 30.38 m. The Hyperion data cube is recorded in 12 bit mode. Radiometric calibration of each data collection event (DCE) includes measurement of a dark current (before and after the DCE) and a lamp illuminated diffuse white calibration panel (after each DCE).

III. HYPERION DATA AND PROCESSING

Cloud-free Hyperion data were collected from the Mount Fitton test site in South Australia on the 27th December 2000. Data were provided by TRW as radiance at sensor. Reduction to ground radiance (apparent reflectance) was achieved using ACORN [5], which is a radiative transfer routine based on MODTRAN. Pixel-based estimates of water vapor are measured using the continuum-depths of the 940 and 1140 nm atmospheric water vapor absorption bands. The resultant retrieval of surface radiance thus relied on sufficient spectral resolution of the atmospheric water bands (only the 1140 nm band used because of complications with the detector overlap in the 900 nm region).

The efficacy of the atmospheric correction was initially assessed through successful recognition of green vegetation spectral signatures along creeks (Figs. 1a and 1b). The overall shape, including the characteristic NIR plateau between 700 and 1300 nm, as well as absorption bands related to chlorophyll (675 nm) and leaf water (980, 1190, 1450 nm) are clearly evident in the reduced Hyperion data.

Information extraction from the reduced Hyperion data, especially from the SWIR region, involved several processes including extraction of scene spectral endmembers using the

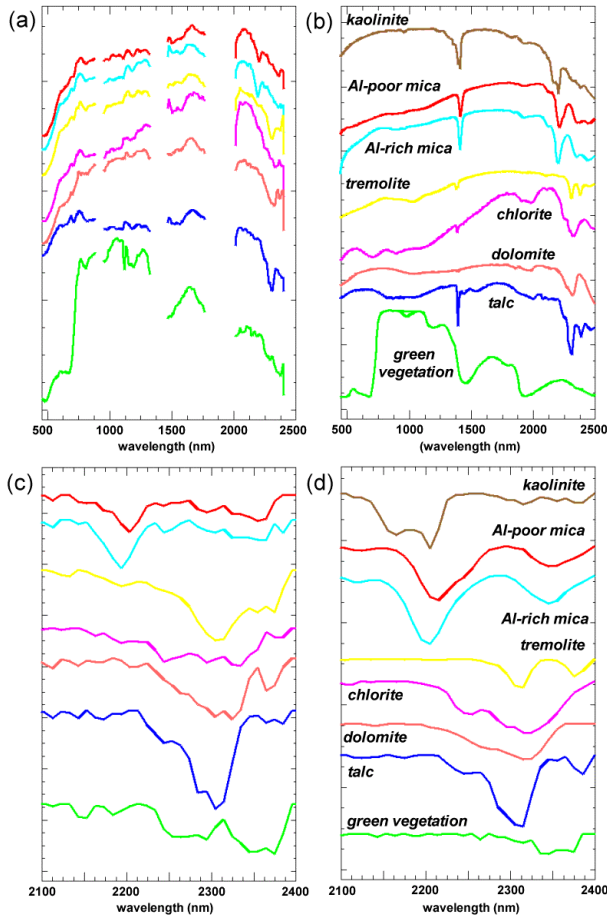


Fig. 1: Stacked spectra offset for clarity (a) Hyperion spectral signatures from selected areas of the Mount Fitton scene. (b) Selected library mineral and green vegetation spectra from [5] convolved to the Hyperion bandpasses. (c) Same as (a) but restricted to the SWIR wavelengths. (d) Same as (b) but restricted to the SWIR wavelengths.

MNF, PPI and n-dimensional approach available in ENVI image processing software [7]. Thresholded partial unmixing (MTMF) products were used to generate mineral theme maps. Derivatives of fitted polynomials (4th order) to diagnostic wavelength ranges were employed to measure a given absorption's area and wavelength information. All derived mineral information products were finally processed to remove outlying classified pixels or fill in holes. The image data were not georeferenced.

IV. GEOLOGY

The semiarid Mount Fitton area is located in the northern Flinders Ranges of South Australia, centered at 139° 25' E and 29° 55' S. Local relief is up to 100 m. Infrequent flash flooding has prevented the development of a deep regolith cover, resulting in abundant exposure of relatively fresh

outcrop. Vegetation is generally low and sparse (5-15% cover), except along ephemeral drainage.

The geology has been mapped by [8]. The published 1:100,000 scale geology map covering the Hyperion overpass of the Mount Fitton talc mines (Fig. 2a) shows the Early Proterozoic Terrapinna Granite, and Late Proterozoic (Adelaidean) sediments of the Umberatana Group, including tillites of the Bolla Bollana Formation, carbonates of the Balcanoona Formation and siltstones and other quartzose sediments of the Amberoona Siltstone, Fortress Hill and other formations. Metamorphic mineralogy is largely controlled by the host rock composition. Calcite within the Balcanoona Formation was converted to dolomite or magnesite, which were altered later during hydrothermal Si metasomatism to locally produce talc (after magnesite), tremolite (after dolomite), quartz, white mica and chlorite.

V. RESULTS

Processing of the 40 SWIR bands between 2000 and 2400 nm for the 1000 lines over the Mount Fitton talc mines (Fig. 2a) yielded only 3 MNF bands without apparent instrument noise (primarily column and random noise) and only 10 with spatially varying geological information (with or without noise). Extraction of spectral endmembers from these data using the n-dimensional visualiser proved difficult with only 3 endmembers clearly distinct from the MNF data cloud. Better results in collecting different mineralogical spectral signatures were achieved using *a priori* knowledge of the geology (locations of these regions of interest are shown in Fig 2.b). This yielded recognisable spectral signatures for most of the minerals expected for the area, including dolomite, talc, chlorite, various white micas and possibly tremolite (Fig. 1a).

The chlorite spectrum shows the characteristic broad ferrous iron absorption centred at 1000 nm similar to that observed in the library chlorite spectrum (Fig. 1b). The SWIR wavelengths of the selected Hyperion mineral spectra (Fig. 1c) show diagnostic absorption bands that allow identification of mineralogy, albeit with spectrally independent noise apparent throughout. For example, the spectrum collected from the talc mine (blue) shows the same deep absorption band at 2310 and accompanying shoulder absorptions at 2290 nm and 2250 nm as the library pure mineral talc spectrum. Chlorite shows a small absorption at 2250 nm, dolomite a broad, left-asymmetric feature centred at 2325 nm and white mica spectra absorption near 2200 nm. However, all spectra show that poorer resolving power at wavelengths greater than 2350 nm, very possibly because of poorer signal to noise.

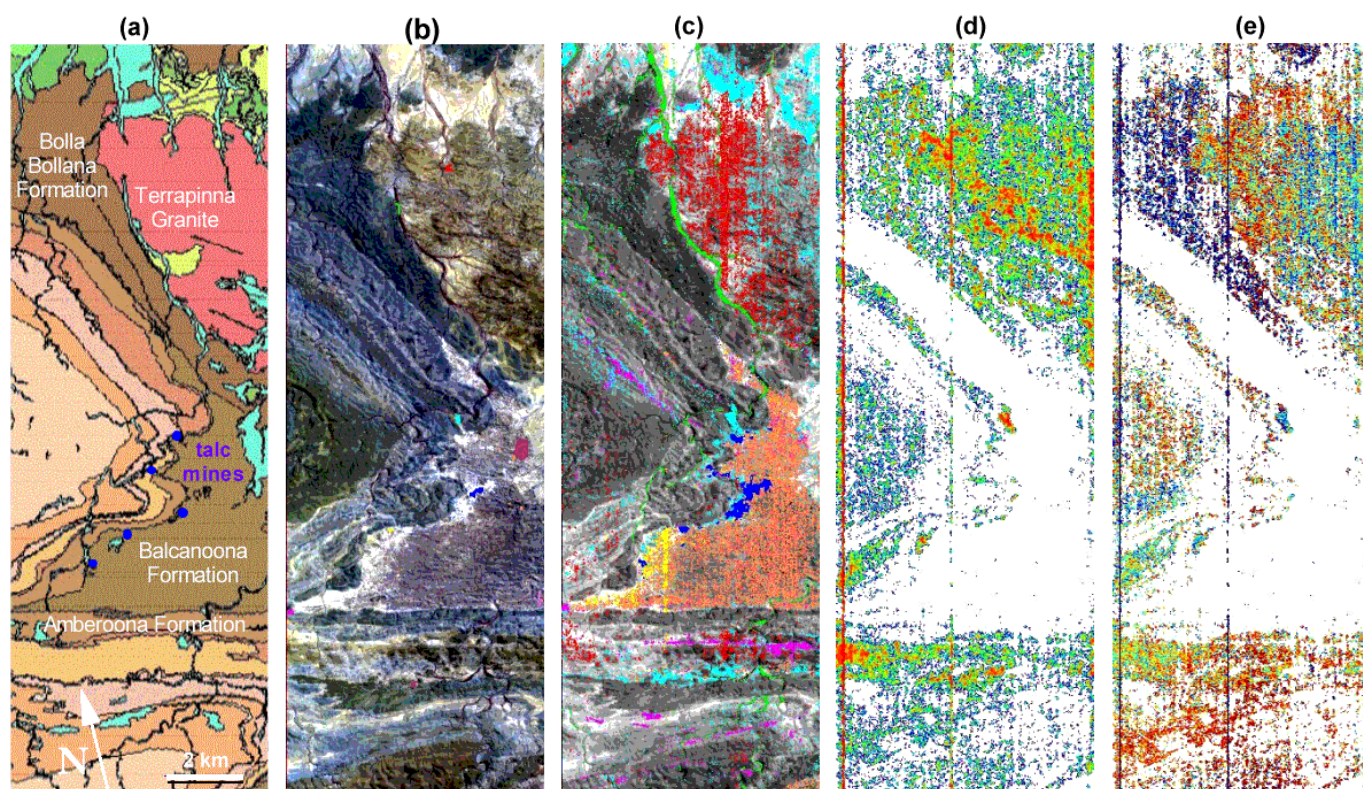


Fig. 2: (a) Published 1:100 000 scale geology [8] of the Mount Fitton test site. (b) Hyperion colour composite image (R: 720 nm; G: 620 nm; B: 550 nm) showing colour-coded regions of interest from which the spectra of Fig. 1a were derived. (c) Mineral map derived using MTMF of the spectral endmembers shown in Fig. 1a. The same colour labels apply. (d) The area of the 2200 nm absorption (blue: small and red: large). (e) Wavelength of the 2200 nm absorption for those pixels with absorption at these wavelengths (Fig. 2d). The wavelength range is from 2190 nm (dark blue) to 2208 nm (red).

The Hyperion derived mineral map (Fig. 2c) shows spatially coherent mineral distributions consistent with the mapped geology as well as superimposed alteration. For example, the dolomites of the Balcanoona Formation are well mapped, as is the white mica rich granite. All the open pit talc mines and related processing plant are accurately mapped. The presence of tremolite, chlorite and white mica towards the western part of the Balcanoona Formation has been established previously by field mapping and represents hydrothermal fluid alteration trapped below the Amberoona Formation.

The white mica absorption near 2200 nm can vary in wavelength depending on the level of Tschermak substitution $\{Al \leftrightarrow Si + (Fe^{2+} \pm Mg)\}$. The Hyperion data were processed to deliver images depicting the area and wavelength of the 2200 nm absorption (abundance and Al-chemistry of white mica, respectively) in Figs. 2d and 2e. These show geologically significant patterns within the granite and quartz-rich sediments and, as expected, essentially absent in the Balcanoona Formation. Note the mapping of Al-poor mica in the Bolla Bollana Formation not apparent in the MTMF results (Figs. 2c, 2d, 2e).

This level of mineral mapping and mineral chemistry mapping based on recognisable spectral signatures is testament to the success of the satellite-borne Hyperion system and its spectral resolving power for mineral mapping.

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